PATENT
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OPTIMAL SPREADER SYSTEM, DEVICE AND METHOD FOR FLUID COOLED MICRO-SCALED HEAT EXCHANGE

RELATED APPLICATION

This Patent Application claims priority under 35 U.S.C. 119 (e) of the co-pending U.S. Provisional Patent Application, Serial No. 60/423,009, filed November 1, 2002 and entitled **"METHODS FOR FLEXIBLE FLUID DELIVERY AND HOTSPOT COOLING BY MICROCHANNEL HEAT SINKS"** which is hereby incorporated by reference. This Patent Application also claims priority under 35 U.S.C. 119 (e) of the co-pending U.S. Provisional Patent Application, Serial No. 60/442,383, filed January 24, 2003 and entitled **"OPTIMIZED PLATE FIN HEAT EXCHANGER FOR CPU COOLING"** which is also hereby incorporated by reference. In addition, this Patent Application claims priority under 35 U.S.C. 119 (e) of the co-pending U.S. Provisional Patent Application, Serial No.60/455,729, filed March 17, 2003 and entitled **MICROCHANNEL HEAT EXCHANGER APPARATUS WITH POROUS CONFIGURATION AND METHOD OF MANUFACTURING THEREOF"**, which is hereby incorporated by reference.

FIELD OF THE INVENTION

This invention relates to the field of heat exchangers. More particularly, this invention relates to systems, devices for, and methods of utilizing spreaders for fluid cooled micro-scaled heat exchange in a optimal manner.

BACKGROUND OF THE INVENTION

Due to the increasing performance of electronic components, there is a need for higher rates of heat removal. These components have increased heat generation and

smaller package sizes. For example, there is a need to dissipate heat from personal computer Central Processing Units (CPUs) in the range of 50 to 200 W.

Forced and natural convection air cooling methods in conjunction with heat sinks currently serve as the predominant method of cooling electronics. The current conventional air cooling systems that use aluminum extruded or die-casting fin heat sinks are not sufficient for cooling the high heat flux of chip surfaces or for large heat dissipation with low thermal resistance and compact size. However, these air-cooled heat sinks require more surface area to effectively function. To be able to transfer the increased heat load, the heat sinks have become larger. To accommodate larger heat sinks, processors use a thermally conductive heat spreader. Unfortunately, the heat spreader increases the overall size of surface area on a printed circuit board required by such an electronic component. This has required the use of larger fans to overcome increased pressure drops. Thus, current cooling methods require substantial space on the one hand, while blocking airflow entry and escape paths on the other.

Furthermore, high aspect ratio fins are used to dissipate heat to the ambient with low thermal resistance. But, there is a need to maintain temperature uniformity in the X-Y direction – a shortcoming of current traditional heat dissipation methods which only transfer heat in one direction.

Therefore, there is a need for a more efficient and effective cooling system. This goal can be reached by the use of liquid cooling methods and devices. A liquid pumped cooling system can remove more heat with considerably less flow volume and maintain better temperature uniformity. These results are reached with significantly less acoustic noise.

SUMMARY OF THE INVENTION

The miniaturization of electronic components has created significant problems associated with the overheating of integrated circuits. Effective cooling of heat flux

levels exceeding 100 W/cm^2 from a relatively low surface area is required. Fluid cooled micro-scaled heat exchangers offer substantial benefits in heat flux removal capability compared with conventional cooling devices. It should be understood that depending on the embodiment of the current invention, the micro-scaled heat exchanger comprises microchannels, a micro-porous structure, or micro-pillars, or is comprised from the group of microchannels, a micro-porous structure, and micro-pillars.

Heat fluxes exceeding 100 W/cm^2 can be removed using the currently disclosed micro-scaled heat exchanger comprising microchannels in silicon or other materials, from heat sources such as a microprocessor, for example. Unlike prior art, the fluid cooled micro-scaled heat exchangers disclosed in the current invention provide extremely high heat transfer area per unit volume in an optimal manner. The micro-scaled heat exchangers of the preferred embodiment of the current invention consist of microchannels with a microchannel walls with width dimensions in the range of and including 10 microns to 100 microns. Alternate embodiments of the micro-scaled heat exchanger include microchannels, a micro-porous structure, or micro-pillars, or are comprised from the group of microchannels, a micro-porous structure, and micro-pillars. The preferred embodiment of the current invention maintains substantial temperature uniformity in the X-Y direction in addition to dissipating heat to the ambient with low thermal resistance. This is accomplished by utilizing high aspect ratio fins that transfer heat to the ambient with low thermal resistance while still maintaining temperature uniformity in the X-Y direction – a shortcoming of current traditional heat dissipation methods which only transfer heat in one direction.

For fluid cooled micro-scaled heat exchangers to provide extremely high heat transfer area per unit volume, the geometric parameters of the exchangers must be considered carefully because these parameters have an influence on the convective heat transfer characteristics. Therefore, designs of systems using the present invention preferably optimize key parameters such as the pressure required to pump the cooling

fluid, the flow rate, the hydraulic diameter of the channel, the temperature of the fluid and the channel wall, and the number of channels. The current invention provides optimized parameters, allowing the fluid cooled micro-scaled heat exchanger to serve as an efficient and economical means for removing high heat per unit volume.

The embodiments of the current invention provide specific types of spreaders used for fluid cooled micro-scaled heat exchange. Specific materials and ranges of dimensions that have been shown through simulations to yield major performance benefits are also disclosed within the current invention. Microchannels with high aspect ratios with depth/width ratios in the range of 10-50 are preferred for the micro-scaled heat exchanger, particularly for single-phase liquid flow. These aspect ratios allow large amounts of fluid to be pumped through the fluid cooled micro-scaled heat exchanger with optimized pressure drop, while simultaneously allowing the fluid to maintain a high thermal convection coefficient to the microchannel sidewalls in the microchanneled embodiment of the current invention.

In the preferred embodiment of the current invention, a spreader region and a micro-scaled region comprise the separate components of the micro-scaled fluid cooled heat exchange device. The spreader region (preferably comprising copper) is preferably interposed between the micro-scaled region (preferably comprising silicon) and the heat source (preferably a microprocessor). In alternate embodiments of the current invention, the spreader region, the micro-scaled region, and the heat source are in a monolithic configuration (i.e. the components of the device consist of, constitute, or are formed from a single unit) and form a monolithic structure. Regardless of the embodiment, the higher thermal conductivity spreader region is wider laterally than the heat source and lies between the micro-scaled region and the heat source and that the micro-scaled overhangs with respect to the heat source (on either side of the heat source) as described more fully below.

The specific width for the micro-scaled and spreader regions are disclosed. In

addition, the current invention discloses specific ranges of optimal dimensions of the micro-scaled and spreader regions that maximize thermal performance.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A illustrates a cross-sectional view of a fluid cooled micro-scaled heat exchanger in which fluid directly contacts the spreader region, in accordance with the instant invention.

FIG. 1B illustrates a perspective view of the of a micro-scaled region having several different heat transferring features in accordance with the present invention.

FIG. 2 illustrates a cross-sectional view schematic of a composite fluid cooled micro-scaled heat exchanger with a manifolding layer, in accordance with the instant invention.

FIG. 3A illustrates a schematic drawing of a composite fluid cooled micro-scaled heat exchanger which includes interwoven manifolds on the top layer, in accordance with the instant invention.

FIG. 3B illustrates a cross-sectional view of the composite fluid cooled micro-scaled heat exchanger shown in FIG. 3A, in accordance with the instant invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The geometric parameters of heat exchangers have a significant influence on their convective heat transfer characteristics. Therefore, designs according to the present invention preferably optimize key parameters of heat exchange such as: the pressure required to pump the cooling fluid; the flow rate; the hydraulic diameter of the channel; the temperature of the fluid and the channel wall; and the number of channels required. The current invention provides optimized parameters, allowing the fluid cooled micro-scaled optimized spreader to serve as an efficient and economical means for dissipating high heat per unit volume.

Embodiments of the current invention provide effective and efficient solutions for optimizing the absolute and relative dimensions of a fluid cooled micro-scaled heat exchanger, its spreader and micro-scaled regions, as well as the overhang of the micro-structure region with respect to a heat source (e.g. a microprocessor). The thickness and width of the micro-scaled region and the spreader region of the current invention balance the vertical thermal resistance of the micro-scaled region and the spreader region against the increase in area for optimized heat transfer into a fluid.

FIG. 1A shows a device 100 for fluid cooled micro-scaled heat exchange from a heat source 101. In the preferred embodiment of the current invention, the heat source 101 is a microprocessor. The fluid preferably comprises water, but in alternate embodiments of the current invention, the fluid is comprised from the group of water, ethylene glycol, isopropyl alcohol, ethanol, methanol, and hydrogen peroxide. Preferably, the device 100 comprises a composite fluid cooled micro-scaled heat exchange region 104 and a spreader region 103, wherein the fluid preferably directly contacts the spreader region 103, as described in greater detail below.

Specifically, the device 100 shown comprises a spreader region 103 and a micro-scaled region 104. The heat source 101 preferably has a width. The micro-scaled region 104 is configured to permit flow of fluid therethrough and has a width and a thickness.

Further, the spreader region 103 has a width and a thickness. In the preferred embodiment of the current invention, the width of the spreader region 103 and the micro-scaled region 104 are greater than the width of the heat source 101.

As disclosed in embodiments of the current invention, the optimal thickness of the spreader region, the dimension H_{SR}, are in the range of 0.3 to 2.0 millimeters. Further, the overhang dimension W_{OH}, otherwise referred to as the difference between either of the widths of the micro-scaled region and the respective heat source, W_s - W_m, is in the range of 0 to 15 millimeters on each side of the heat source. The height of the micro-scaled region 104, H_{MS}, is discussed in detail below. The actual value chosen depends on many considerations such as manufacturing cost, for example.

The micro-scaled region 104 is configured to permit flow of fluid therethrough. The micro-scaled region 104 preferably comprises microchannels, wherein the microchannels comprise walls, but in alternate embodiments comprises a micro-porous structure, or micro-pillars, or is comprised from the group of microchannels, a micro-porous structure, and micro-pillars. The spreader region 103 of the present invention is alternatively utilized in conjunction with a heat exchanger described in co-pending patent application Serial No. 10/680,584, filed on October 6, 2003, and entitled "METHOD AND APPARATUS FOR EFFICIENT VERTICAL FLUID DELIVERY FOR COOLING A HEAT PRODUCING DEVICE", which is hereby incorporated by reference. In addition, more details of the microchannels, micro-pillars, and micro-porous structures can be found in co-pending patent application Serial No. Cool-01800, filed on __________, and entitled "METHOD AND APPARATUS FOR ACHIEVING TEMPERATURE UNIFORMITY AND HOT SPOT COOLING IN A HEAT PRODUCING DEVICE", which is hereby incorporated by reference.

FIG. 1B illustrates a perspective view of the micro-scaled region 104 coupled to the spreader region 103. The micro-scaled region 104 shown in FIG. 1B has several different heat transferring features in accordance with the present invention. The micro-

scaled region 104' includes multiple microchannels 10, wherein two of the microchannels are of the same shape and one microchannel 12 has a portion extending taller than the other portion. Further, the microchannels 14 are located a further distance away from one another compared to the distance between microchannels 10 and 12. In addition, the micro-scaled region 104' includes several micro-pillars 20 and 22 of various height dimensions disposed thereon in accordance with the present invention. As shown in Figure 1B, the micro-pillars 22 extend vertically from the bottom surface of the micro-scaled region 104' to a predetermined height, potentially the entire height of the micro-scaled region 104'. The micro-pillars 20 extend vertically an amount less than the micro-pillars 22. The micro-pillars 22 can have any shape including, but not limited to, pins (Figure 1B), square (not shown), diamond (not shown), elliptical (not shown), hexagonal (not shown), circular or any other shape. The micro-scaled region 104' alternatively has a combination of differently shaped micro-pillars disposed thereupon. In addition, Figure 1B illustrates a micro-porous structure 30 disposed on the micro-scaled region 104'.

It is apparent that the micro-scaled region 104' can include one type of heat transferring feature or alternatively any combination of different heat transferring features (e.g. microchannels, micro-pillars, micro-porous structures).

The preferred embodiment of the current invention comprises microchannels, wherein the microchannels comprise walls, with heights (i.e., direction normal to the heat source) H_{MS} in the range of 50 microns - 2 millimeters and widths of the microchannel walls in the range of 10 - 150 micrometers. The current manufacturing techniques that can achieve these aspect ratios include plasma etching and LIGA manufacturing. Most of these techniques are currently dedicated to semiconductor manufacturing (primarily silicon). In the preferred embodiment of the current invention, the micro-scaled region 104 comprises silicon. Silicon offers a reasonably high thermal conductivity (~120 W/m-K), which allows the heat to conduct effectively up the sidewalls of the microchannels. In alternate embodiments of the current invention, the micro-scaled region 104 comprises

a material with thermal conductivity larger than 25 W/m-K. In yet other embodiments, the micro-scaled region 104 comprises a semiconducting material. Alternate materials for the micro-scaled region 104 providing adequate aspect ratios include, but are not limited to, silicon, germanium, silicon carbide, precision machined metals and alloys, or composites/combinations. Further, the spreader region 103 preferably comprises copper. Copper (~ 400 W/m-K) is the preferred material for the spreader region 103 because of cost and thermal conductivity considerations, although diamond (~ 2000 W/m-K), silver (~ 430 W/ m-K) , aluminum (~ 395 W/m-K), silicon carbide (~ 400 W/m-K), or a combination/composite may also be utilized. It is important to note that any material with a thermal conductivity equal to or greater than silicon allowing for heat spreading by the spreader region 103 can be used for the spreader region 103. In alternate embodiments of the current invention, the spreader region 103 comprises a material with a thermal conductivity value larger than 200 W/m-K.

The spreader region 103 comprises a first side 103' and a second side 103". The first side 103' is positioned on and coupled to the heat source 101 and the second side 103" is coupled to the micro-scaled region 104. Preferably, the first side 103' is coupled to the heat source 101 via a thermal attachment means 102 and the second side 103" is coupled to the micro-scaled region 104 via a second thermal attachment means 102'.

In alternate embodiments of the current invention, the spreader region 103, the micro-scaled region 104, and the heat source 101 are in a monolithic configuration and form a monolithic structure.

In order to achieve a minimal thermal resistance between the fluid in the micro-scaled region 104 and the heat released by the heat source 101 (e.g., a microprocessor), it is preferred for the heat to spread slightly, laterally, as it moves from the heat source 101 to the micro-scaled region 104. Thus, the spreader region 103, as well as the first and second thermal attachment means 102 and 102' preferably comprise a high thermal conductivity material. In addition, the use of slightly larger lateral dimensions for the

spreader region 103, such that the total area for heat absorption by the fluid is augmented, is also preferred. Thus, the optimal thickness and width of the spreader region 103 and the micro-scaled region 104 balance the vertical thermal resistance of the spreader 103 against the increase in area for heat transfer into the fluid, as disclosed below. The dimensions are also determined by whether there is single phase (e.g., only liquid) or two phase (e.g., liquid and boiling liquid) cooling occurs and by the configuration of the micro-scaled region 104. The three tables below provide preferred dimensions depending on the configuration of the micro-scaled region 104 as well as on the phase of cooling occurring.

TABLE 1

Micro-scaled region (comprising a micro-porous structure) and Spreader region properties	Single Phase	Two Phase
Thickness of spreader region	0.3 - 0.7 mm	0.3 - 1.0 mm
Average Size of Pore	10 - 200 micron	10 - 200 micron
Porosity of micro-porous structure	50 - 80 %	50 - 80 %
Height of micro-scaled region	0.25 - 2.0 mm	0.25 - 2.0 mm
Overhang of micro-scaled region with respect to heat source width	0 - 5.0 mm	0 - 15.0 mm

TABLE 2

Micro-scaled region (comprising micro-pillars) and Spreader region properties	Single Phase	Two Phase
Thickness of spreader region	0.3 - 0.7 mm	0.3 - 1.0 mm
Cross sectional area of micro-pillar	(10 micron)^2 - (100 micron)^2	(10 micron)^2 - (100 micron)^2
Separation between micro-pillars	10 - 150 micron	10 - 150 micron
Height of micro-pillar	50 - 800 micron	50 - 2.0 mm
Overhang of micro-scaled region with respect to heat source width	0 - 5.0 mm	0 - 15.0 mm

TABLE 3

Micro-scaled region (comprising microchannels) and Spreader region properties	Single Phase	Two Phase
Thickness of spreader region	0.3 - 0.7 mm	0.3 - 1.0 mm
Width of micro-channel wall	10 - 100 micron	10 - 100 micron
Separation between micro-channel walls	10 - 150 micron	10 - 150 micron
Height of micro-channel wall	50 - 800 micron	50 - 2.0 mm
Overhang of micro-scaled region with respect to heat source width	0 - 5.0 mm	0 - 15.0 mm

It should be understood that the optimal dimensions listed in the Tables 1, 2, and 3 are a function of the material and fluid properties. However, it will be appreciated that the optimal dimensions listed will be adjusted by the practitioner if materials or fluids

other than those discussed in the current invention are utilized.

The spreader region 103 and the micro-scaled region 104 can be attached (as shown by the first and second thermal attachment means 102 and 102') using any of a variety of methods including, but not limited to, anodic bonding, brazing, soldering, and bonding by epoxy.

As stated above, the micro-scaled region preferably comprises microchannels, wherein the microchannels comprise walls. At least one of the microchannels has a height dimension within the range of and including 50 microns and 2 millimeters and at least two of the microchannels are separate from each other by a spacing dimension within the range of and including 10 to 150 microns. The preferred microchannels comprises at least one of the microchannels has a width dimension within the range of and including 10 to 150 microns.

In alternate embodiments, the micro-scaled region comprises a micro-porous structure. The micro-porous structure comprises a porous material with a porosity within the range of and including 50 to 80 percent, with the micro-porous structure having an average pore size within the range of and including 10 to 200 microns. The micro-porous structure alternate embodiment comprises a height within the range of and including 0.25 to 2.0 millimeters.

In yet another embodiment, the micro-scaled region comprises micro-pillars. The micro-pillars comprise a plurality of pins, wherein at least one of the plurality of pins has an area dimension within the range of and including $(10 \text{ micron})^2$ and $(100 \text{ micron})^2$. At least one of the plurality of pins has a height dimension within the range of and including 50 microns and 2 millimeters, and at least two of the plurality of pins are separated from each other by a spacing dimension within the range of and including 10 to 150 microns. It should also be understood that in another alternative, the micro-scaled region is comprised from the group of microchannels, a micro-porous structure, and micro-pillars.

FIG. 2 illustrates a cross-sectional view schematic of a composite fluid cooled micro-scaled heat exchanger with a manifolding layer, in accordance with the instant invention. Specifically, FIG. 2 shows an alternate embodiment of the current invention, wherein the device 200 comprises a heat source 201, a thermal attachment means 202, a spreader region 203 with a first side 203' and a second side 203", a second thermal attachment means 202', a micro-scaled region 204, and a manifolding layer 205. The fluid enters and exits the device 200 via the inlet/outlet 206. The micro-scaled region 204 is configured to receive fluid from the inlet/outlet 206 and permit flow of fluid through the micro-scaled region 204. The micro-scaled region 204 preferably comprises microchannels, wherein the microchannels comprise walls, but alternatively, may comprise a micro-porous structure, or micro-pillars, or is comprised from the group of microchannels, a micro-porous structure, and micro-pillars. The preferred micro-scaled region 204 microchannels comprise depths (direction normal to the heat source) in the range of 50 microns to 2 millimeters and widths in the range of 10 - 150 micrometers. The micro-scaled region 204 walls preferably comprise a silicon material. Alternative materials available for use for the microchannel walls include silicon carbide, diamond, any material with thermal conductivity larger than 25 W/m-K, a semiconducting material, or other materials discussed above.

The spreader region 203 comprises a first side 203' and a second side 203". The first side 203' is positioned on and coupled to the heat source 201 and the second side 203" is coupled to the micro-scaled region 204. Preferably, the first side 203' is coupled to the heat source 201 via a thermal attachment means 202 and the second side 203" is coupled to the micro-scaled region 204 via a second thermal attachment means 202'. The first and second thermal attachment means 202 and 202' preferably comprise high thermal conductivity material. The spreader region 203 and the micro-scaled region 204 (or the spreader region 203, the micro-scaled region 204, and manifolding layer 205), can be attached (as shown, for example, by the first and second thermal attachment means 202

and 202') using any of a variety of methods including, but not limited to, anodic bonding, brazing, soldering, and bonding by epoxy. In alternate embodiments of the current invention, the spreader region 203, the micro-scaled region 204, the manifolding layer 205, and the heat source 201 are in a monolithic configuration and form a monolithic structure.

The spreader region 203 comprises copper, although diamond, silver, aluminum, and silicon carbide, a composite, or the other materials described above may also be utilized. Further, any material, or composite with a higher thermal conductivity than silicon (i.e., thermal conductivity values larger than 200 W/m-K) can be used for the spreader region 203.

The manifolding layer 205 comprises interwoven manifolds preferably coupled to the micro-scaled region 204. In other embodiments, these interwoven manifolds are coupled to the spreader region 203 alone, or, alternatively, to both the micro-scaled region 204 and the spreader region 203. The manifolding layer 205 preferably comprises glass. The manifolding layer 205 illustrated in the FIG. 2 could also be utilized in other embodiments of the current invention. In alternate embodiments, the manifolding layer comprises a plurality of individualized holes for channeling fluid into and out of the heat exchange device. The details of manifolding layers and various embodiments of the manifolding layers are discussed in co-pending patent application Serial No. 10/680,584, filed on October 6, 2003, and entitled "METHOD AND APPARATUS FOR EFFICIENT VERTICAL FLUID DELIVERY FOR COOLING A HEAT PRODUCING DEVICE", which is hereby incorporated by reference.

The current invention also discloses a method for fabricating a fluid cooled micro-scaled heat exchange device comprising fabricating a micro-scaled region comprising silicon, fabricating a spreader region comprising copper, and coupling the micro-scaled region with the spreader region. In alternate methods, the micro-scaled region and the spreader region are monolithic, as described above. The preferred method entails

fabricating the micro-scaled spreader region from precision machined metals. In alternate methods, the micro-scaled spreader region is fabricated from precision machined alloys.

Further, a system for fluid cooled micro-scaled heat exchange is disclosed. The system (not shown) comprises a heat source, means for spreading heat, means for supplying fluids, and means for micro-scaled fluid flow. The means for spreading heat is coupled to the heat source. The means for micro-scaled fluid flow is configured to receive fluid from the means for supplying fluid. The means for micro-scaled fluid flow preferably comprises microchannels, wherein the microchannels comprise walls, but in alternate embodiments, comprises a micro-porous structure, or micro-pillars, or is comprised from the group of microchannels, a micro-porous structure, and micro-pillars. microchannels. The means for micro-scaled fluid flow is coupled to the means for spreading heat.

FIG. 3A illustrates a more detailed drawing of the embodiment comprising a composite fluid cooled micro-scaled heat exchange device with interwoven manifolds on the top layer, in a geometry similar to FIG. 2. Specifically, FIG. 3A shows a device 300. The device 300 comprises a spreader region 301, a first manifolding layer 302, a plurality of first manifolding layer fluid paths 302', a second manifolding layer 303, a plurality of second manifolding layer fluid paths 303', and a micro-scaled region 304. In one embodiment, the device 300 size is approximately 18 mm x 12 mm x 3 mm. The microchannel region 304 height is 300 micron, the width is 50 micron, and the base is 200 micron. The spreader region 301 is 300 micron thick and preferably copper. The heat source (not shown) is approximately 0.725 millimeter wide. The first and second manifolds are approximately 2 millimeter wide and 10 millimeter long, with fluid paths in the range of 0.4 - 0.8 millimeter wide. The materials used for the first and second manifold layers are preferably glass, but may include copper, kovar, or glass. The fluid paths 302' and 303' comprise inlets and outlets configured to receive fluid, at a minimum, from the first and second manifolding layers. It will be appreciated that the dimensions

recited are exemplary and other dimensions can be used for heat sources with other sizes.

FIG. 3B shows a monolithic heat exchange device 310. The device 310 comprises a heat source 301, a spreader region 302, a micro-scaled region 303, a first manifolding layer 304, a second manifolding layer 305, and a top manifold 306. In one embodiment, the height from the micro-scaled region 303 to the top of the top manifold 306 is approximately 3 millimeters while the height from the micro-scaled region 303 to the top of the first and second manifold layers 304 and 305 is approximately 2 millimeters. It will be appreciated that the dimensions recited are exemplary and other dimensions can be used for heat sources with other sizes.

Unlike prior art, the fluid cooled micro-scaled heat exchangers disclosed in the current invention provide extremely high heat transfer area per unit volume in an optimal manner. Further, the current invention maintains substantial temperature uniformity in the X-Y direction in addition to dissipating heat to the ambient with low thermal resistance. Another advantage of the current invention is that it uses a spreader region to enhance lateral spreading of heat leaving the heat source, together with the micro-scaled region to achieve high aspect ratio structures that aid with transferring heat to the fluid creating a optimal composite material fluid cooled micro-scaled heat exchanger.

The present invention has been described in terms of specific embodiments incorporating details to facilitate the understanding of the principles of construction and operation of the invention. Such reference herein to specific embodiments and details thereof is not intended to limit the scope of the claims appended hereto. It will be apparent to those skilled in the art that modifications may be made in the embodiment chosen for illustration without departing from the spirit and scope of the invention.